

Wind Turbine Gearbox Condition Monitoring Round Robin



NREL PIX 19018

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Outline

- Background
 - Field test of GRC #1 gearbox
 - Opportunities for condition monitoring (CM)
 - Objectives and approach
- Test Gearbox
- Test Setup
- Preliminary Data Validation
- Logistics
- Status
- Partners
- Real Damage
- Performance Evaluation Rules

Background: Field test of GRC #1 gearbox

- First finished run in in the NREL 2.5 MW dynamometer
- Sent to the Ponnequin Wind Farm for field tests
- Two oil spills: led to damages in gears and bearings
- Further field tests: more harm than benefits to the GRC project

Background: Opportunities for CM

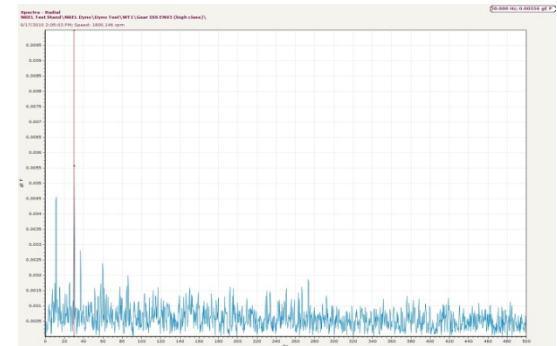
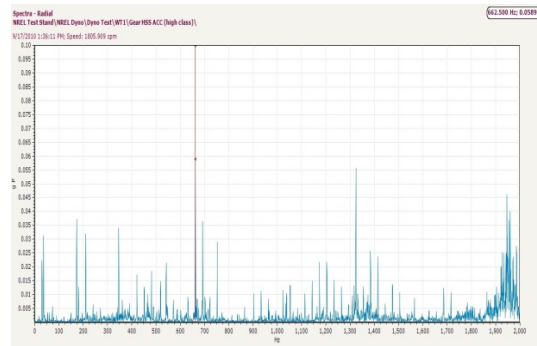
- If retested in the dynamometer under controlled conditions:
 - Collect data for evaluation of different technologies investigated by the GRC already
 - Enable a CM round robin study for evaluating different vibration data analysis algorithms



NREL 2.5 MW Dynamometer/PIX16913

Background: Objectives

- Evaluate different vibration analysis algorithms and find out whether the typical practices are effective
- Assess the capability of vibration-based CM and to establish a baseline from which improvements can be measured

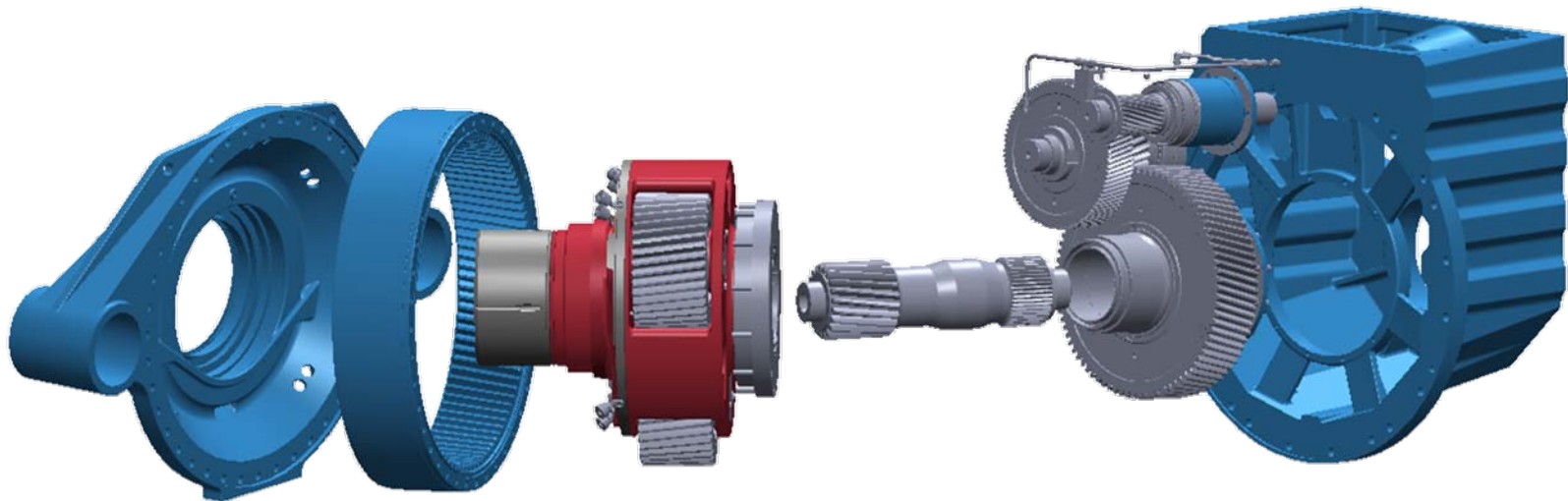


Background: Approach

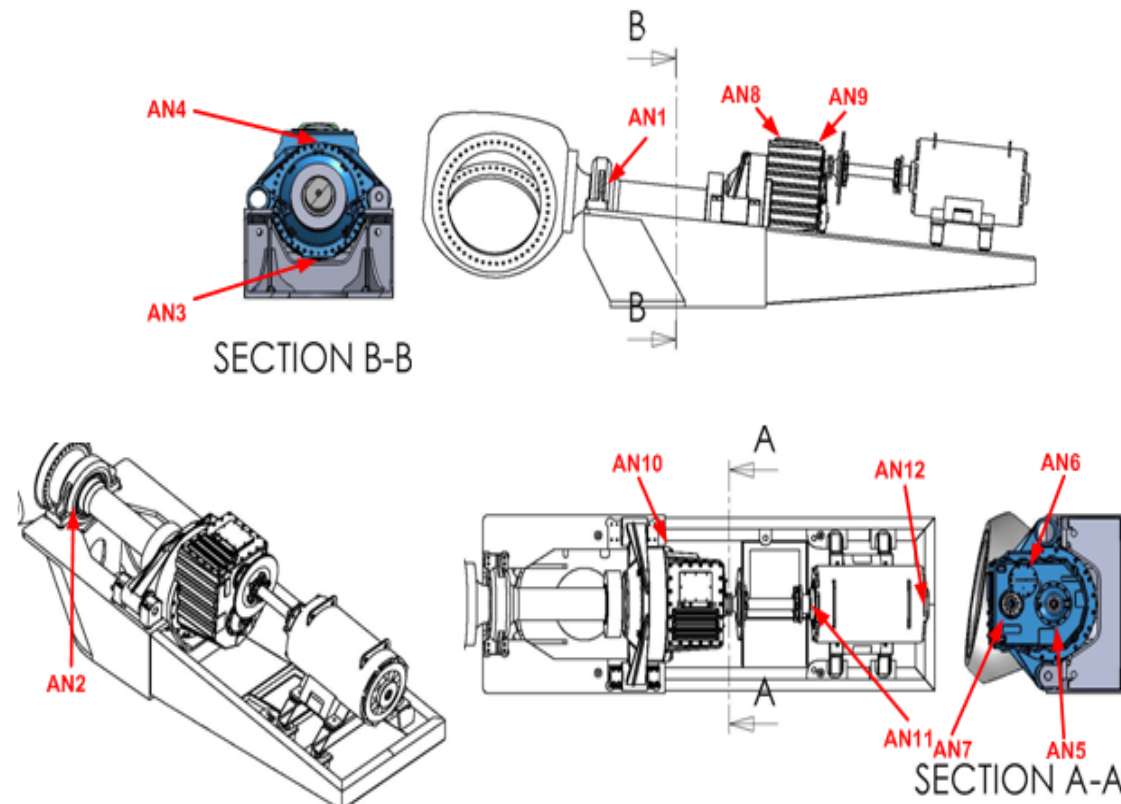
- MOU
- Data shared
- Results submitted
- True failure information disclosed
- Comparison of results
- Detailed report and publications
- **Uniqueness:** A blind study that the analysts will not see the true failures until their results are submitted to NREL.

Test Gearbox

- Rated at 750 kW
 - One planet stage and two parallel stages
 - Redesign
 - ❑ Floating sun, cylindrical roller planet bearings, tapered roller bearings in parallel stages, pressurized lubrication, offline filtration and desiccant breather
 - Up to 150 channels of measurements for loads, displacements, and temperature



Test Setup: Sensor Placement



Sensor Label/ Signal Name	Description
AN1	Main bearing radial
AN2	Main bearing axial
AN3	Ring gear radial 6 o'clock
AN4	Ring gear radial 12 o'clock
AN5	LSS radial
AN6	ISS radial
AN7	HSS radial
AN8	HSS upwind bearing radial
AN9	HSS downwind bearing radial
AN10	Carrier downwind radial
AN11	Generator upwind radial
AN12	Generator downwind axial

- Two Typical Configurations Used by the Industry: both have 8 sensors; difference is replacing AN 5 to 7 by AN 8 to 10.

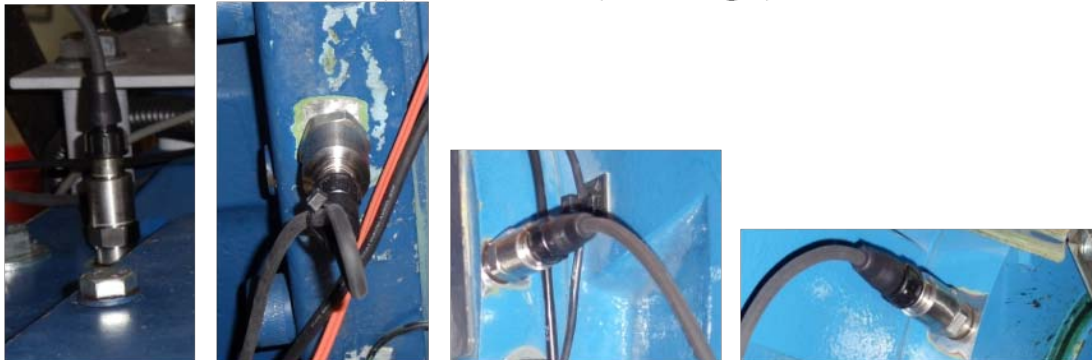
Test Setup: Test Conditions



(a) AN1 to AN4 (Left to Right)



(b) AN5 to AN8 (Left to Right)

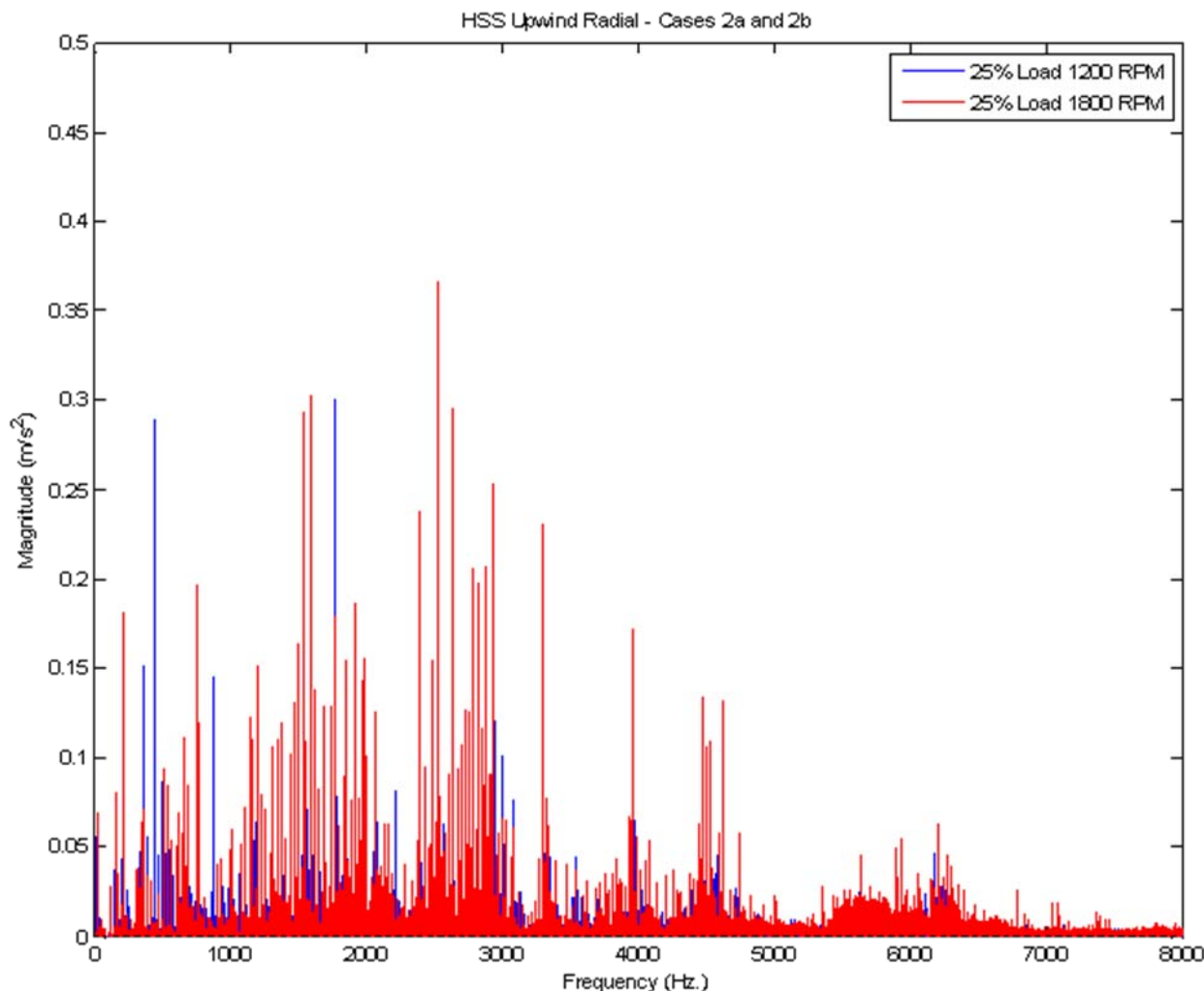


(c) AN9 to AN12 (Left to Right)

Test case	Nominal HSS Speed (rpm)	Electric Power (% of rated)
CM_2a	1200	25%
CM_2b	1800	25%
CM_2c	1800	50%

- Two types of accelerometers: 500 mV/g and 100 mV/g
- All channels sampled at 40 kHz
- Each case tested for 10 minutes
- Each data file: 1 minute of data, 14 channels including 12 accelerometers, one rpm and one torque

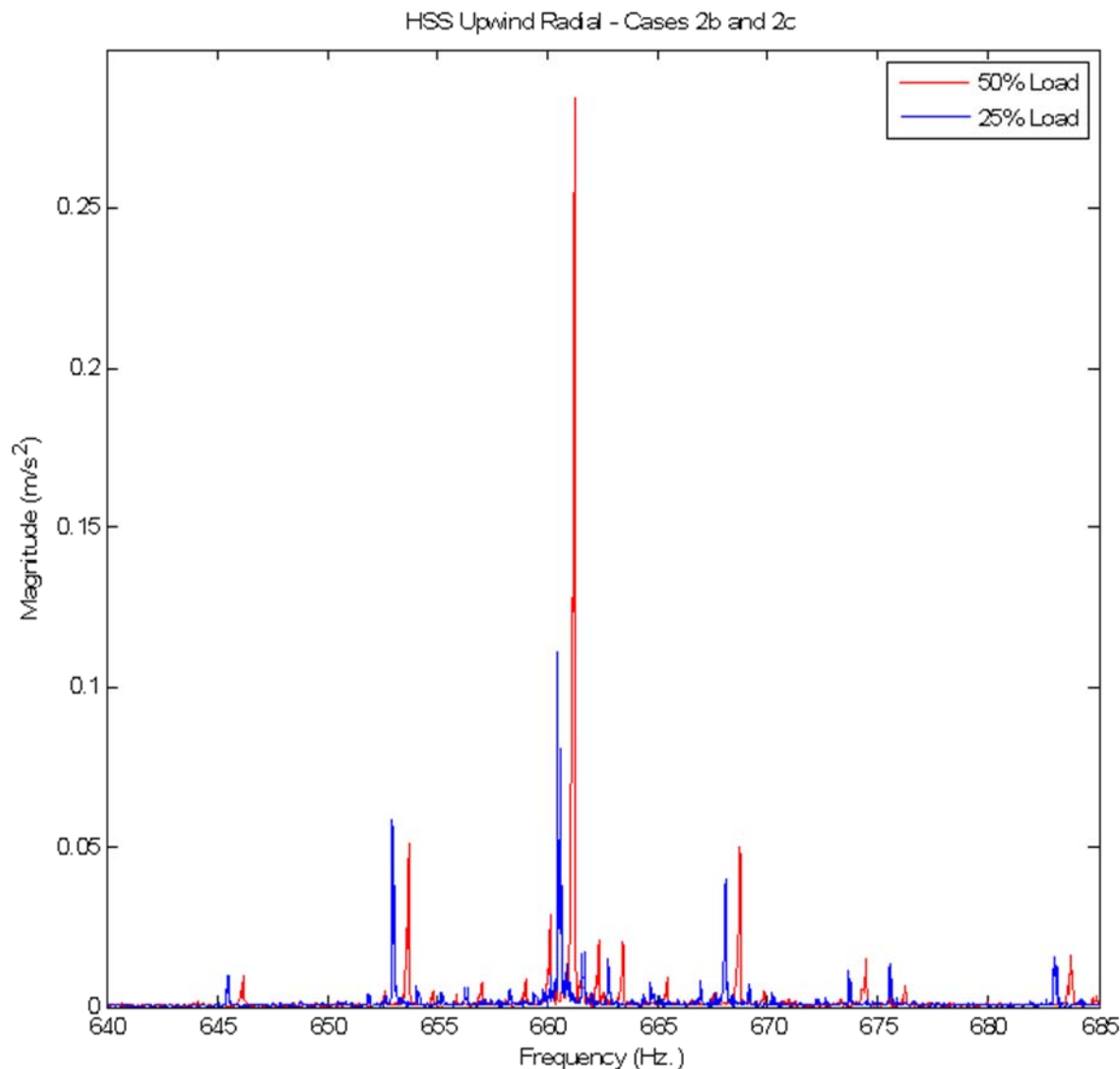
Preliminary Data Validation



- 0-8 kHz spectrum for AN8_HSSFrontRadial, cases 2a and 2b;
- Lots of spectral content;
- Most of the fundamental gear mesh frequencies stand out very prominently along with their harmonics;
- Predicted frequencies match measured frequencies.

Credit: Robb Wallen

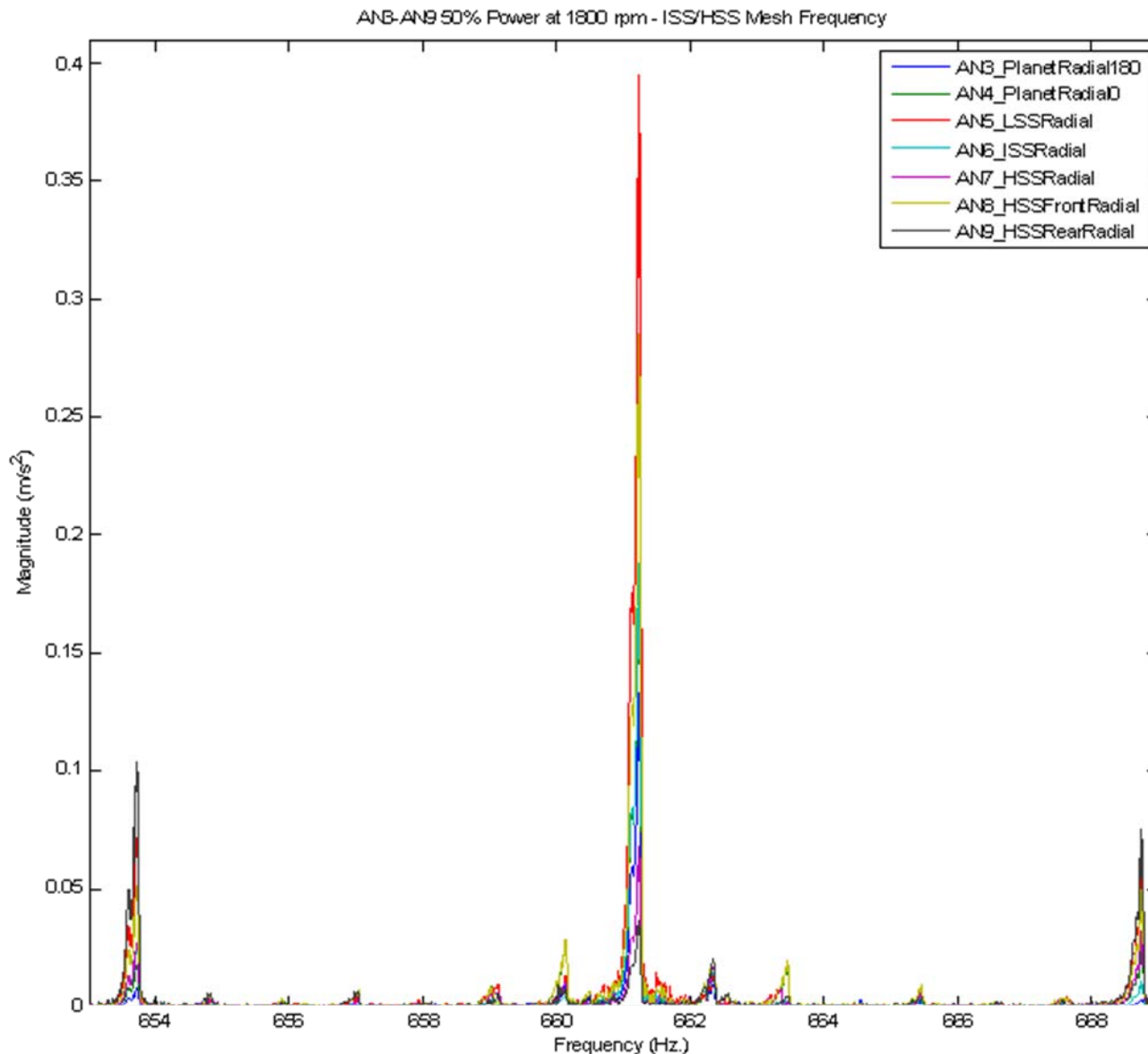
Preliminary Data Validation



- Detail of ISS/HSS mesh frequency for cases 2b and 2c from sensor AN8_HSSFrontRadial.
- Fundamental mesh frequency prominent.
- Frequency shift between 2b and 2c correct due to generator slip.
- Change in relative magnitudes reasonable given increased loads.
- Side bands at ± 7.5 Hz, modulation by the 450 rpm (7.5 Hz) ISS shaft.

Credit: Robb Wallen

Preliminary Data Validation



- Sensors AN3 through AN9 at the ISS/HSS mesh frequency, case 2c.
- The relative magnitudes of each sensor vary with location, but they all appear to detect the same vibration signatures (frequency components).

Credit: Robb Wallen

Logistics

■ Results Submittal Formats:

Failure	Component/ Location	Mode	Severity	Rationale	Notes
1					
2					
3					
4					
⋮					

■ Algorithms Evaluated by Two Ratios:

- Correct Diagnostics/True Failures
- False Alarms/True Failures

■ Schedule:

- Data release February 1 – April 1, 2011
- Results submission April 18-30, 2011
- Results comparisons June 30, 2011
- Detailed report March 31, 2012

Status

- Partners: 16
- Geographic distribution: 3 Europe, 1 Australia, and 12 United States
- Agency type distribution: 7 universities and 9 private sectors
- Further results fine tuning underway by each partner
- Detailed reports inputs solicited from each partner
- Papers for the confirmed wind energy journal special issue solicited: 50% rejection rate

Partners

- Brüel & Kjær Vibro A/S
- Colorado School of Mines
- GE Energy Services
- Impact Technologies
- IVC Technologies
- National Instruments
- NRG Systems Inc.
- Purdue University
- Schenck Corporation
- Sentient Corporations
- STC Consultants (SKF)
- University of Cincinnati
- University of Connecticut
- University of Iowa
- The University of New South Wales, Australia
- Wichita State University

Real Damage Used in Evaluation

Failure #	Component / Location	Mode	Severity
1	HSS Gear Set	Scuffing	Severe
	(HSS Gear and HSS Pinion)		
2	HSS Downwind Bearings	Overheating	Mild
	(IR and Rollers)		
3	ISS Gear Set	Fretting Corrosion	Severe
	(ISS Gear and Pinion)	Scuffing	
	(All Teeth)	Polishing Wear	
	(Sun Spline)		
4	ISS Upwind Bearing	Assembly damage	Moderate
	(IR)	Plastic deformation	
		Scuffing	
		False brinelling	
		Debris dents	
		Contact Corrosion	
5	ISS Downwind Bearings	Assembly damage	Severe
	(OR Spacer for both Bearings)	Plastic deformation	
		Dents	
6	Annulus/Ring Gear, or Sun Pinion	Scuffing and polishing	Moderate
		Fretting Corrosion	Severe
7	Planet Carrier Upwind Bearing	Fretting Corrosion	Severe
	(Container and OR)		

Real Damage Not Used in Evaluation

8	Sun Pinion Thrust Rings	Fretting Corrosion	Moderate
	(Upper Spherical Thrust Ring)	Adhesive Wear	
	(Lower Spherical Thrust Ring)		
9	Oil Transfer Ring for Planet Carrier	Polishing	Mild
	(Bore)		
10	LSS	Scuffing	Severe
	(Shaft and O-ring Seal Plate)		
11	LSS Downwind Bearings	Abrasion	Severe
	(Locknut)		
12	HSS Shaft	Misalignment	Mild

Rationale: Vibration-based techniques may not be able to identify damage #8 to #11.

Algorithms Performance Evaluation Rules

1. The diagnosis results evaluated are only those obtained during the blind study stage.
2. Without visual inspection, it is hard for vibration-based techniques to tell whether it is scuffing, corrosion, etc. An indication of damage is considered acceptable. Damage severity level will not be considered in the results evaluation.
3. For a certain stage of the gearbox, it may be hard to identify the specific damaged elements. A measure down to stage level is considered acceptable.

Stay tuned, performance evaluation results will be disclosed during wrap up discussion this afternoon.

Acknowledgements

- DOE Financial Support
- Partners: valuable results provided without being paid
- GRC Team, Especially:
 - Paul Veers and Jeroen van Dam: vision and support
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 - Brian McNiff and Bill LaCava: project description document